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Abstract of Report on General Double-Galvanized Steel Strand and Iron Wire for Overhead Transmission and Distribution

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Abstract of Report
on
Tests *of* Double Galvanized Steel St
and
Iron Wire
for Electrical Transmission
and Distribution

Indiana Steel and Wire Company
Muncie, Indiana, U. S. A.

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PREFACE

Gift

There has been widespread inquiry for informatio concerning the use of double galvanized iron wire an steel strand for transmission purposes.

The mechanical properties of iron wire and stee strand are well known but their electrical characteristics under various conditions have not received as much investigation.

We have had run a series of tests on steel strand and iron wire to determine their electrical characteristics and adaptability and are pleased to submit an abstract of these tests and a set of tables showing the electrical properties of samples tested.

There are many cases where iron wire and strand can be, and are being successfully used in power lines, with reliability and economy.

Just when and how depends on local conditions and is purely an engineering problem but the following treatise should aid you materially in solving your own individual problems.

This pamphlet covers in a general way the very points that have been uppermost in the minds of Engineers and should fill a real want in the field of Transmission Line Engineering.

We have prepared in cloth bound volume a more elaborate treatise on these tests which we shall be pleased to furnish gratis if you are further interested.

INDIANA STEEL AND WIRE COMPANY

March 1, 1921

Abstract of Report

on

Tests *of* Double Galvanized Steel Strand

and

Iron Wire

for Electrical Transmission

and Distribution

Purpose of Tests. The object of these tests was to determine the electrical properties of certain representative sizes and grades of steel cable and wire, with continuous currents and with sine-wave alternating currents, under a range of conditions such that the results would be applicable in designing transmission and distribution lines in which steel conductors might be employed with advantage.

Test Samples. The following sizes and grades of galvanized steel conductors were submitted by the Indiana Steel and Wire Co. for test.

⅜ in. "High Strength" Strand.
½ in. "Siemens-Martin" Strand.
⅜ in. "Siemens-Martin" Strand.
¼ in. "Siemens-Martin" Strand.
⅜ in. "Standard" Strand.
3 Ply No. 8 Twisted Guy Wire.
No. 6 B. W. G. "B. B." Telegraph Wire.

Properties With Continuous Currents

The following table shows the composition and cross-section of each sample, the resistance in ohms per mil-foot and ohms per mile of conductor at 20 deg. Cent., the conductivity ratio to standard copper and the temperature coefficient of resistance from and at a temperature of 20 deg. Cent. or 68 deg. Fahr.

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Table of Properties With Continuous Currents

Manufacturer's Designation	Number of Wires	Average Diameter of Wire (Mils)	Total Circular Mils in Conductor	Resistance at 20 Deg. Cent.		Conductivity Ratio to Copper*	Temperature Coefficient of Resistance Per Deg. Cent. From and at 20 Deg. Cent.
				Ohms Per Mil-Foot	Ohms Per Mile of Cond'ctr		
⅜ in. High Strength Strand	7	119.5	99,960	107.3	5.67	9.67%	0.00338
½ in. Siemens-Martin Strand	7	159.3	177,600	112.8	3.35	9.20%	0.00333
⅜ in. Siemens-Martin Strand	7	119.5	99,960	104.1	5.50	9.97%	0.00348
¼ in. Siemens-Martin Strand	7	81.85	46,900	108.0	12.2	9.61%	0.00309
⅜ in. Standard Strand	7	125.0	109,400	69.8	3.37	14.85%	0.00570
3 Ply No. 8 Twisted Guy Wire	3	162.2	78,930	79.5	5.32	13.05%	0.00445
No. 6 B.W.G. "B.B." Telegraph Wire	1	202.0	40,800	68.3	8.84	15.18%	0.00496

*International Annealed Copper Standard

Properties With Alternating Currents

Wires of any material offer both resistance and reactance to alternating currents. Theoretically the alternating-current resistance is always greater than the continuous-current resistance, the increase ranging from practically nothing under certain conditions to many times the continuous-current resistance under other conditions. Values of resistance determined from measurements with alternating currents are termed effective resistances in order to distinguish them from the true or continuous-current resistance and should always be employed in place of the latter in alternating-current calculations. The reactance of a conductor transmitting alternating current depends upon the character of the conductor, the frequency and the separation or spacing from the return conductor. Therefore it is necessary, in stating the effective reactance of a power line conductor at some given frequency, to state the separation from its parallel return conductor.

The alternating-current tests on the samples of steel conductors before described were made with waves of sine shape and therefore the results stated in the tables which follow will be understood as applying exclusively to sine waves or waves of substantially that form. While no tests were made with waves of distorted shape, or containing harmonics, it is safe to assume that severe distortion would change the values of effective resistance and reactance appreciably, always tending to increase them. The following tables show the ratio of alternating-current resistance to continuous-current resistance, the effective alternating-current resistance per mile, the line loss in watts per mile and the effective reactance per mile at six different spacings, for frequencies of 25 and 60 cycles per second, with currents of 5, 10, 15, 20, and 25 amperes. The values of effective resistance include the heating effect in the conductor when suspended in an atmosphere having a temperature of 20 deg. Cent. or 68 deg. Fahr.

⅜-Inch High Strength Steel Strand

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A.C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.006	5.871	147	1.016	1.100	1.149	1.184	1.211	1.233
10	1.007	5.892	589	1.040	1.124	1.173	1.208	1.235	1.257
15	1.011	5.935	1335	1.062	1.146	1.195	1.230	1.257	1.279
20	1.013	5.977	2391	1.086	1.170	1.219	1.254	1.281	1.303
25	1.016	6.030	3769	1.112	1.196	1.245	1.280	1.307	1.329
25 CYCLES									
5	1.002	5.834	146	0.424	0.459	0.480	0.494	0.506	0.515
10	1.001	5.840	584	0.434	0.469	0.490	0.504	0.516	0.525
15	1.001	5.861	1319	0.445	0.480	0.501	0.515	0.527	0.536
20	1.003	5.935	2374	0.456	0.491	0.512	0.526	0.538	0.547
25	1.005	5.993	3746	0.468	0.503	0.524	0.538	0.550	0.559

½-Inch Siemens-Martin Steel Strand

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A.C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.012	3.400	85	1.005	1.089	1.138	1.173	1.200	1.222
10	1.014	3.421	342	1.028	1.112	1.161	1.196	1.223	1.245
15	1.015	3.427	771	1.044	1.128	1.177	1.212	1.239	1.261
20	1.019	3.443	1377	1.059	1.143	1.192	1.227	1.254	1.276
25	1.021	3.474	2171	1.084	1.168	1.217	1.252	1.279	1.301
25 CYCLES									
5	1.004	3.374	84	0.427	0.462	0.482	0.497	0.508	0.517
10	1.005	3.379	338	0.431	0.466	0.486	0.501	0.512	0.521
15	1.006	3.390	763	0.440	0.475	0.495	0.510	0.521	0.530
20	1.007	3.400	1360	0.448	0.483	0.503	0.518	0.529	0.538
25	1.007	3.411	2132	0.457	0.492	0.512	0.527	0.538	0.547

⅜-Inch Siemens-Martin Steel Strand

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A. C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.008	5.444	136	1.033	1.117	1.166	1.201	1.228	1.250
10	1.009	5.465	547	1.066	1.150	1.199	1.234	1.261	1.283
15	1.011	5.491	1235	1.099	1.183	1.232	1.267	1.294	1.316
20	1.016	5.549	2220	1.128	1.212	1.261	1.296	1.323	1.345
25	1.017	5.623	3514	1.156	1.240	1.289	1.324	1.351	1.373
25 CYCLES									
5	1.002	5.423	136	0.430	0.465	0.486	0.500	0.512	0.521
10	1.003	5.433	543	0.446	0.481	0.502	0.516	0.528	0.537
15	1.004	5.470	1231	0.459	0.494	0.515	0.529	0.541	0.550
20	1.005	5.512	2205	0.471	0.506	0.527	0.541	0.553	0.562
25	1.006	5.565	3478	0.482	0.517	0.538	0.552	0.564	0.573

¼-Inch Siemens-Martin Steel Strand

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A.C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.002	12.25	306	1.105	1.189	1.238	1.273	1.300	1.322
10	1.003	12.38	1238	1.131	1.215	1.264	1.299	1.326	1.348
15	1.006	12.54	2822	1.175	1.259	1.308	1.343	1.370	1.392
20	1.008	12.75	5100	1.203	1.287	1.336	1.371	1.398	1.420
25	1.009	13.04	8150	1.252	1.336	1.385	1.420	1.447	1.469
25 CYCLES									
5	1.001	12.20	305	0.462	0.497	0.517	0.532	0.543	0.552
10	1.001	12.30	1230	0.473	0.508	0.528	0.543	0.554	0.563
15	1.002	12.51	2815	0.489	0.524	0.544	0.559	0.570	0.579
20	1.003	12.72	5088	0.503	0.538	0.558	0.573	0.584	0.593
25	1.006	13.02	8138	0.526	0.561	0.581	0.596	0.607	0.616

⅜-Inch Standard Steel Strand

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A.C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.080	3.912	98	1.727	1.811	1.860	1.895	1.922	1.944
10	1.130	4.071	407	1.984	2.068	2.117	2.152	2.179	2.201
15	1.207	4.367	983	2.275	2.359	2.408	2.443	2.470	2.492
20	1.346	4.979	1992	2.629	2.713	2.762	2.797	2.824	2.846
25	1.512	5.634	3521	2.890	2.974	3.023	3.058	3.085	3.107
25 CYCLES									
5	1.036	3.733	93	0.822	0.857	0.878	0.892	0.904	0.913
10	1.064	3.844	384	0.983	1.018	1.039	1.053	1.065	1.074
15	1.117	4.071	916	1.182	1.217	1.238	1.252	1.264	1.273
20	1.191	4.382	1753	1.399	1.434	1.455	1.469	1.481	1.490
25	1.250	4.620	2887	1.552	1.587	1.608	1.622	1.634	1.643

3-Ply No. 8 B. W. G. Twisted Guy Wire

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A.C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.059	5.734	143	2.006	2.090	2.139	2.174	2.201	2.223
10	1.102	5.987	599	2.404	2.488	2.537	2.572	2.599	2.621
15	1.179	6.426	1446	2.896	2.980	3.029	3.064	3.091	3.113
20	1.275	7.091	2836	3.449	3.533	3.582	3.617	3.644	3.666
25	1.345	7.577	4736	3.907	3.991	4.040	4.075	4.102	4.124
25 CYCLES									
5	1.018	5.512	138	0.831	0.866	0.866	0.901	0.912	0.922
10	1.034	5.613	561	1.002	1.037	1.057	1.072	1.083	1.093
15	1.073	5.887	1325	1.280	1.315	1.335	1.350	1.361	1.371
20	1.152	6.362	2545	1.581	1.616	1.636	1.651	1.662	1.672
25	1.195	6.706	4191	1.910	1.945	1.965	1.930	1.991	2.001

This conductor is made up of three No. 8 B. W. G. wires twisted together.

No. 6 B. W. G. "Best-Best" Telegraph Wire

(Per Mile of Conductor)

Current in Amperes	Ratio of A. C. Resistance to D. C. Resistance	Effective (A. C.) Resistance in Ohms Per Mile	Line Loss in Watts Per Mile	Effective Reactance in Ohms Per Mile at Different Spacings					
				12 in.	24 in.	36 in.	48 in.	60 in.	72 in.
60 CYCLES									
5	1.525	13.41	335	7.716	7.800	7.850	7.884	7.912	7.934
10	1.950	17.21	1721	8.610	8.694	8.744	8.778	8.806	8.828
15	1.990	17.82	4010	8.791	8.875	8.925	8.959	8.987	9.009
20	1.900	17.56	7024	8.741	8.825	8.875	8.909	8.937	8.959
25	1.760	17.00	10630	8.384	8.468	8.518	8.552	8.580	8.602
25 CYCLES									
5	1.281	11.30	283	4.169	4.204	4.225	4.239	4.251	4.260
10	1.508	13.46	1346	5.678	5.713	5.734	5.748	5.760	5.769
15	1.494	13.57	3053	5.777	5.812	5.833	5.847	5.859	5.868
20	1.433	13.28	5312	5.711	5.746	5.767	5.781	5.793	5.802
25	1.373	13.17	8233	5.592	5.627	5.648	5.662	5.674	5.683

Discussion of Results

The seven samples represented in these tests are divisible as a whole into two classes, with rather marked difference in characteristics. The first group comprises the samples of "High Strength" and "Siemens-Martin" strands, ranging in size from ¼ inch to ½ inch diameter. These four samples are quite similar in their properties both with continuous currents and with alternating currents. The conductivity (D. C.) ranges from 9.20% to 9.97% of standard copper and the increase of resistance with alternating currents is merely nominal, reaching a maximum of 2.1% for the largest strand at the highest current density and the upper frequency. The reactances at the different spacings are roughly double the corresponding values for copper conductors of equal size.

The second group comprises the samples of "Standard" strand, 3 ply guy wire and No. 6 "B. B." wire. Their conductivity (D. C.) ranges from 13.05% to 15.18% of standard copper, but they all exhibit pronounced increase of resistance with alternating currents at the higher values of current used, particularly in the case of the No. 6 "B. B." wire, whose maximum alternating-current resistance at 60 cycles is double its continuous-current resistance. The values of reactance in the case of the "Standard" strand and the 3 ply guy wire are roughly three to six times the corresponding values for copper of equal size, but the relative values of reactance for the No. 6 "B. B." wire are much higher.

These differences in characteristics are readily accounted for by differences in the relative hardness of the several grades of steel. The harder and stronger steels, such as "High Strength" and "Siemens-Martin", have relatively lower conductivity, nominal increase of resistance with alternating currents and moderate values of reactance. The softer steels, such as "Standard" strand, guy wire and "B. B." wire, have conductivities

(D. C.) approaching that of pure iron, but their increase of resistance with alternating currents is very marked and their reactances are relatively high. It is self-evident that in considering the use of steel power conductors, or in calculations relative to their efficiency, effective values of alternating-current resistance and reactance should invariably be used.

Conclusions

The economic field for the use of steel power conductors depends upon the prevailing market prices of the conductor materials from which a choice would ordinarily be made, as well as upon engineering considerations relating both to fundamental principles and to local conditions in each specific case. Under normal market prices there is an economical field of considerable proportions for the use of steel conductors.

From the electrical standpoint the use of steel is determined by the same fundamental considerations with respect to line losses, regulation, carrying capacity and corona discharge as would apply in the case of any other conductor, with due regard also for the physical characteristics of the material. In general the feasible applications of steel conductors may be summarized under situations of the following types.

(a) For power lines of short or moderate length operated at very high tension, where the minimum permissible size of conductor is one sufficiently large to avoid corona discharge, the line resistance being a secondary consideration.

(b) For high-tension lines of short or medium length transmitting moderate amounts of energy, such that the line drop and loss fall within permissible limits, as for example in the case of branch or tap lines of high-tension networks.

(c) For short lines delivering small amounts of energy at the primary voltages customary in urban and rural distribution, such that the drop and the loss are not excessive.

(d) For long or unusually severe spans requiring greater tensile strength and factor of safety than can be obtained with copper or aluminum.

Respectfully submitted,

Frank F Fowle

Consulting Engineer

Chicago, Ill.,
March 1, 1921

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